(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 January 2001 (18.01.2001)

PCT

(10) International Publication Number
WO 01/05084 A1

(51) International Patent Classification[7]: H04J 14/02, 14/08, 14/00, G02B 6/35, 6/26, G02F 1/01, H01S 3/08, 5/32

(21) International Application Number: PCT/US00/18763

(22) International Filing Date: 10 July 2000 (10.07.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/142,892 8 July 1999 (08.07.1999) US

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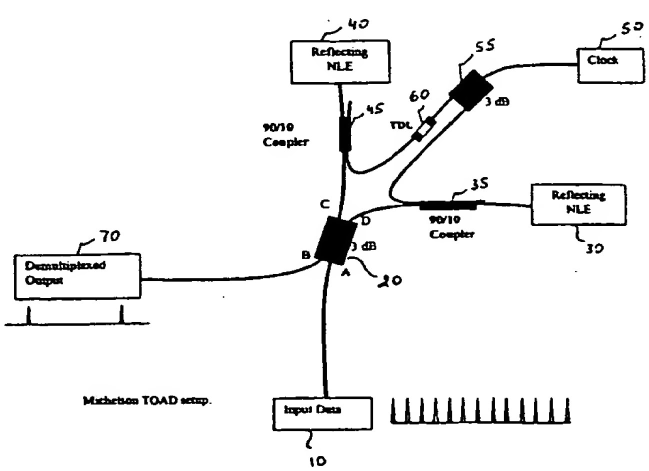
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: TERAHERTZ OPTICAL ASYMMETRIC DEMULTIPLEXING SYSTEM AND METHOD



(57) Abstract: An optical demultiplexer has a coupler (20) connected to first optical path that has a first reflecting nonlinear optical element (NLE), which responds to a control pulse to induce a 180 degree phase shift in an optical data signal propagating therethrough. A second optical path is connected to the coupler, which includes a second similar reflecting NLE. Optical pulses provided at an input port of the coupler propagate through both optical paths and, when reflected, experience either constructive or destructive interference dependent on the state of the NLEs. A control input (50) induces a first control pulse in the first optical path and a second control pulse in the second optical path, the second control pulse delayed a time Δt from the first control pulse, so that a data pulse (10) propagating through the first path is phase delayed by 180 degrees by the first NLE but experiences no additional phase delay in the second NLE. Embodiments are described in which the reflecting NLEs are implemented either as integrated components, or alternatively using reflective mirrors separate from the NLE. Different schemes for providing the control input are also disclosed.

WO 01/05084 A1

TERAHERTZ OPTICAL ASYMMETRIC DEMULTIPLEXING SYSTEM AND METHOD

This application claims priority of U.S. provisional application Ser. No. 60/142,892 filed July 8, 1999.

Field of the Invention

The present invention relates generally to ultrafast optical switching and more specifically to an optical demultiplexer capable of selecting individual pulses from a time-division multiplexed input pulse train having data rate in the terabit per second range, and a corresponding method for optical demultiplexing.

Background of the Invention

The performance of ultrafast, optical time-division multiplexed (OTDM) communication networks depends critically on the accurate recovery of timing information, which is performed using high-bandwidth demultiplexing. Broadly, in OTDM systems binary signals from several transmitters are multiplexed onto a single optical path, such as an optical fiber. Typically, each transmitter is assigned one time slot within a data frame, where each time slot corresponds to a bit of data. To extract data from a particular transmitter (i.e., data channel), a demultiplexing switch is used at the receiving end to sample the time slot corresponding to the transmitter in each data frame. A separate switch is required for each received channel. Clearly, the demultiplexing switch must have sufficient bandwidth to permit sampling of data in the time slot and must perform a sampling operation every frame. Because such demultiplexers are the only components of the network that operate at rates corresponding to the optical system's aggregate bandwidth, they are also the components that primarily limit the achievable signal throughput. The same observation also holds in the case of optical packet switching networks, where data along with routing information is encoded in optical packets, which flow through multiple communication nodes before reaching their ultimate destination. The network has a higher capacity if the optical packets are temporally compressed. However, in such networks an optical demultiplexer is required to read individual bits of information within the packet, thus limiting the achievable throughput of the packet-switched network.

Several approaches have been suggested in the prior art for ultrafast demultiplexing of optical pulses to enable switching of pulses that are several hundred femtoseconds long. One example is the Ultrafast Nonlinear Interferometer (UNI), developed at MIT Lincoln Labs, which is an all-optical OTDM switch using a semiconductor optical amplifier (SOA) as a nonlinear element in a single-arm interferometer. The UNI has a long birefringent fiber used to separate orthogonally polarized components of data pulses in time using accurately timed control pulses. While the UNI approach is capable of providing very high data throughput, its integratability and thus practicality are limited by the long length of birefringent fiber needed to induce the polarization walk-off.

Another examples are provided by different existing embodiments of the Terahertz Optical Asymmetric Demultiplexer (TOAD) developed at Princeton University, which is a versatile, high performance all optical switch. The reader is directed, for example, to U.S. Pat. Nos. 5,917,979; 5,841,560; 5,825,519; 5,493,433; 5,073,980 and 5,060,305 for further detail. The disclosure of the above patents is incorporated herein for all purposes. While the above and other references disclose significant advances in the field of optical switching, alternative approaches that may take advantage of currently developed technologies would be beneficial in certain practical applications.

Accordingly, it is an object of this invention to provide a novel optical demultiplexer system and method for operation in the terabit per second range. Another object is to provide an optical demultiplexer that can be compact and generally compatible with integrated semiconductor elements.

Summary of the Invention

An optical demultiplexer in a preferred embodiment has a coupler connected to a first optical path that has a first reflecting nonlinear optical element (NLE), which responds to a control pulse to induce a phase shift in an optical data signal propagating therethrough. A second optical path is connected to the coupler, which includes a similar reflecting NLE. Optical pulses provided at an input port of the coupler propagate concurrently through both optical paths and, when reflected, experience at the coupler either constructive or destructive interference dependent on the state of the first and second NLE. In a specific embodiment, a control input induces a first control pulse in the first optical path and a second control pulse in the second optical path, the second control pulse delayed a time Δt

from the first control pulse, so that a data pulse propagating through the first path is phase delayed by 180 degrees by the first NLE but experiences no additional phase delay in the second NLE. In this manner, an optical pulse in a high data rate optical pulse train can be selected, and forwarded to an output port of the device. Embodiments are described in which the reflecting NLEs are implemented either as integrated components, or alternatively using reflective mirrors separate from the NLE. Different schemes for providing the control input are also disclosed.

In particular, in one aspect of the invention an optical demultiplexer is disclosed comprising: a first optical path having a first nonlinear optical element (NLE) and a reflective mirror; a second optical path having a second NLE and reflective mirror, where the first and second NLE responsive to an optical control pulse to induce a phase shift in an optical data pulse propagating through them. The demultiplexer also comprises an optical coupler having an input port for concurrently coupling a train of optical data pulses onto the first and second optical paths, the coupler being responsive to in-phase data pulses reflected from the first and second optical paths to provide an output data pulse on a first output terminal, and to phase-offset data pulses reflected from the first and second optical paths to provide an output data pulse on a second output terminal. The demultiplexer also comprises a control circuit providing optical control pulses with predetermined timing to the first and second NLE to direct output data pulses to a select output terminal.

In another aspect, an optical demultiplexer is disclosed comprising a coupler concurrently coupling a train of input optical data pulses to one end of a first and a second optical paths; a first non-linear optical element (NLE) and an associated mirror at an opposite end of the first optical path and a second NLE and an associated mirror at an opposite end of the second optical path; and a control circuit providing control signals that cause changes in the optical properties of the first NLE in a predetermined timing relationship to changes in the optical properties of the second NLE to direct in-phase optical pulses reflected from the first and the second optical paths to a select output terminal.

In yet another aspect, a method for optical demultiplexing is disclosed comprising the steps of providing an input optical data pulse train comprising time-division multiplexed signals from a plurality of channels; passing the input optical data pulse train concurrently through one end of a first and second optical paths, each path having at an opposite end a non-linear optical element (NLE) and an associated reflecting mirror; applying an optical

control pulse in a predetermined timing relationship to each NLE to cause reflected optical data pulses propagating through the first and second optical paths to interfere constructively; and directing optical pulses resulting from the constructive interference to a select output terminal.

Brief Description of the Drawings

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which like elements are designated with like reference numerals, and:

Fig. 1 is a schematic diagram illustrating one embodiment of an optical demultiplexer system in accordance with the present invention;

FIG. 2 is a waveform diagram helpful in understanding the operation of the demultiplexer in accordance with the present invention;

FIGs. 3, 4 and 5 are schematic block diagrams of different embodiments of the demultiplexer system in accordance with the present invention.

Detailed Description of the Preferred Embodiments

The Michelson Terahertz Optical Asymmetric Demultiplexer (TOAD) in accordance with the present invention is an optically-controlled optical switch that is capable of demultiplexing data from a terabit per second optical data stream. As illustrated in Figure 1, the Michelson TOAD in a specific embodiment splits an input optical data pulse from an input module 10 into two separate paths (C) and (D) using a 3-dB coupler 20. As shown, coupler 20 has an input port A and two ports C and D connected to the corresponding optical paths. In accordance with the present invention each optical path has at another end a Nonlinear Element (NLE) and a mirror, which reflect the optical data pulse back to the 3-dB coupler 20. As illustrated in Fig. 1, in a specific embodiment, the NLE and the mirror of each optical path can be combined into a reflecting NLE 30 and 40, respectively. In accordance with the invention, a control pulse is injected into each of the reflecting NLE's 30, 40 either through a coupler along the optical path, as illustrated in the embodiment of Fig. 1, or through a second input at the NLE, as illustrated in Figs. 3 and 4.

In particular, in the embodiment shown in Fig. 1 the control pulse from a source generally designated as clock 50 is injected through couplers 35, 45 along the optical paths C and D. As shown, in a preferred embodiment couplers 35 and 45 are 90/10 couplers, which permit the use of strong control pulses. It will be appreciated, that the type of coupler used in a particular application is a design choice that depends on the relative strength of the data and clock signals. Thus, the selection of 90/10 coupler in the specific embodiment shown in Figs. 1 and 5 reflects the concern that data signals are typically relatively weak, and it is desirable to avoid any attenuation. Clearly, however, other choices, such as 60/40 are possible in alternative embodiments.

NLEs 30, 40 used in accordance with this invention exhibit an optical non-linearity with an extremely fast rise time and may have a relatively slow fall time. Generally, the rise time must be less in duration than the bit time slot of an incoming data train and the fall time must be less than the frame time, so as enable the NLE in each optical path to be prepared for a next bit time slot in a next frame. It should be noted that the relaxation time of the non-linearity of NLE 30, 40 does not have to be smaller than the bit period, which is the case in many prior art optical switch configurations. NLE 30 and 40 may be any optical device that exhibits a rapid change in an optical non-linearity in response to an applied energy pulse. In various embodiments, the optical non-linearity may be evidenced by a change in refractive index, attenuation, or other optical phenomenon. Examples of currently available NLEs are discussed below, as well as in the above-referenced patents, which are incorporated by reference. It will be appreciated, however, that the principles of the present invention are applicable to any material or device that performs in the described manner, so that the descriptions herein are not limiting.

In the embodiment shown in Fig. 1, a gating pulse is applied from clock 50 to the optical switch via couplers 35, 45. The control pulse injected in the NLE causes a very fast response - preferably a change in the index of refraction of the material - and the NLE then relaxes back into its original state, typically at a slower rate.

In operation, an optical time domain-multiplexed (OTDM) signal train is applied to the optical demultiplexer via an OTDM input 10. The signal is split in coupler 20 and propagates concurrently in optical paths C and D until it is reflected by the mirror of the reflecting NLEs 30, 40. After reflection, the optical data pulses recombine at the 3-dB coupler 20. In accordance with a preferred embodiment, the lengths of the optical paths

(arms of the interferometer) are calibrated in advance. In one embodiment, the calibration may be such that when the pulses recombine in coupler 20, constructive interference occurs at input port A and destructive interference occurs at port B. Alternatively, the calibration may result in constructive interference that occurs at port B and destructive interference at port A. In other words, the interferometer may be balanced so that output pulses can come out from either port A or port B, depending on the desired configuration. In accordance with the present invention, the data pulses can then be switched to the other port if a control pulse is applied to change the state of the reflecting NLE on only one optical path, so that the pulse on this path experiences an additional 180^0 phase shift. It will be appreciated that Figs. 1, 3, 4 and 5 reflect one type of calibration of the interferometer, where constructive interference normally occurs at the input port. Clearly, if the other type calibration is used, the demultiplexed output may coincide with the input port, and in order to recover the output signal, another coupler can be used to separate it from the input signal.

In short, the Michelson TOAD in accordance with the present invention performs fast demultiplexing of the desired channel by using the rapid response time of the NLE. In one embodiment, a mode-locked laser can be used to provide both the data and the control pulses. In alternative embodiments data and control pulses may be provided using different lasers. It should be apparent that where different lasers are used, it would be necessary to synchronize their operation, so that data pulses corresponding to a desired channel can be selectively extracted from the input data train. Details of such synchronization should be apparent to one of skill in the art and will therefore not be discussed in further detail. The reader is directed to for such details, for example, to the disclosure of the above-identified patents incorporated by reference.

At the control end, a pulse is split in a 50/50 coupler 55 and injected into both reflecting NLEs of the Michelson TOAD. It should be apparent that the strength of the provided control signal depends on the NLE and in practice would be selected to trigger the non-linearity of the NLE. The relative arrival time of the two control pulses into each optical path is offset by a time Δt. As illustrated in Fig. 1, in a preferred embodiment the difference in arrival time (which may be due to the different length of the optical paths, to temperature or other properties of the optical paths) can be tuned externally using a tunable delay line (TDL) 60. The reader is directed for further detail to Kung-Li Deng, et al. "A 1024-Channel Fast Tunable Delay line for Ultrafast All-Optical TDM Networks", IEEE

Photonics Technology Letters, V9, no11, Nov. 1997, which article is hereby incorporated by reference.

The detailed operation of the optical demultiplexer in accordance with this invention will now be described in conjunction with the waveform diagrams shown in Fig. 2. Figure 2 shows how the difference in arrival time can switch out the desired channel in time. In particular, with the exception of the pulse within the time window Δt (solid pulse), all the pulses experience the same phase shift at the NLEs 30, 40, regardless of whether the NLEs are in the relaxed state or the excited state. With reference to the illustration shown in Fig. 1, experiencing the same phase shift in the NLEs in the two optical paths causes the recombined pulse to exit from the input port A. The pulse within the time window Δt (solid pulse) in Fig. 2 experiences different properties of the NLE at the two optical paths, however. Since the control pulses arrive at one of the NLE Δt ahead of the other NLE, optical data arriving at the two NLEs within Δt will acquire an additional 180^0 phase shift at the 3-dB coupler and switch out the recombined pulse from output port B. The time slot Δt can be made arbitrarily small (subject to practical limitations) by decreasing the difference in path lengths, and therefore the arrival times, of the control pulse. As noted above, in a preferred embodiment the time slot to be switched can also be tuned very easily and rapidly to difference channels using devices, such as the fast TDL 60.

It will be appreciated that a practical limitation on the switching speed of the device is the rise time of the nonlinear effect and the transit time across twice the length of the NLE. As known in the art, for currently available materials the rise time is typically on the order of 100fs; whereas the transit time depends on the physical dimension of the device used and is usually less than a picosecond. Using these numbers as guidelines, it can be verified that the Michelson TOAD of the present invention can perform terabit switching. Clearly, future-developed NLEs having improved characteristics can be used instead in accordance with the principles of this invention.

In addition to the approach shown in Figure 1, in accordance with the present invention the control pulse can also be injected into the NLEs in both optical paths directly through a second port. One embodiment using this approach is illustrated in Fig. 3, where like reference numerals designate like elements. In an alternative embodiment the control pulse can be injected through the back of the NLE, as shown in Fig. 4. Different embodiments are possible dependent on the structure and the properties of the NLE, the

availability of a second input port. In practical applications the selection of the type of NLE and the way in which control pulses are injected in it would be determined by considerations including how well the structure integrates, on its cost, performance, etc.

Figure 5 shows an alternative embodiment of the present invention in which the NLEs 30, 40 can be physically separated from the mirrors 32, 42. Generally, separating the elements may be a more cost-effective approach. It should be noted, however, that it also effectively extends the transit time across the NLE to include the separation distance between the NLE and the mirror, and therefore acts to reduce the achievable throughput of the device. With the NLE separated from the mirror, the setup also allows the possibility of injecting the control pulse from the same input as the data, as the difference in arrival time at the NLE is determined by their relative position in each optical path. For a comparable principle of operation, the reader is directed to the Mach-Zehnder TOAD configuration disclosed, for example, in U.S. Pat. No. 5,825,519.

In accordance with the present invention in all embodiments discussed above it may be necessary to filter out control pulses from the output. To this end, in one embodiment one can use control pulses having orthogonal polarization with respect to the data pulse, and then provide a polarization filter. In an alternative embodiment, one can use control pulses having different wavelength. compared with the data pulses, and use a corresponding filter to remove the control data wavelengths from the output data stream. In either case, with reference to Fig. 1, for example, such filter can be positioned between port B of the coupler 20 and the demultiplexed output 70. For details on filtering the control signal output the reader is directed to the above-identified U.S. patents, the relevant disclosure of which is incorporated herein for all purposes.

In accordance with various embodiments, the Michelson TOAD of the present invention can use an interferometer based on free space optics with discrete components, fiber optics with discrete components, or integrated optics combining optical waveguides and nonlinear elements on the same substrate, as known in the art. The discrete components consist of optical fiber cables, optical couplers, polarizers, polarization splitters, optical filters, and a mode-locked laser that provides the control pulses. In a specific embodiment, the reflecting NLE can be made from a semiconductor optical amplifier (SOA) with one reflecting surface, a saturable Bragg reflector (SBR), or other reflecting nonlinear devices.

In one preferred embodiment, the NLE is implemented using vertical cavity surface emitting laser(s) (VCSEL).

In accordance with the present invention, another approach to building a Michelson TOAD is to integrate the optical waveguides, using either semiconductor materials, Lithium Niobate, or glass (SiO_2) as the substrate. In a semiconductor material the active components preferably can be fabricated on the same surface with the optical waveguides. The most common semiconductor material used is InGaAsP, where enabling technologies such as re-growth, tapered waveguide, and Twin Waveguide allows both the passive components and the active components to be fabricated on the same chip. In addition to semiconductors, glass waveguides employ a hybrid implementation that uses both discrete and integrated components where slots are left opened in the waveguides for the insertion of the nonlinear element. The use of the aforementioned components and integration technologies allow the Michelson TOAD to be realized as ultrafast optical demultiplexer that can be monolithically integrated and compactly packaged. Various techniques are envisioned for use in accordance with the principles of the present invention, dependent on the specific practical application.

While the invention has been described with respect to the preferred embodiments, those skilled in the art will recognize that numerous variations and modifications may be made without departing from the scope of the invention. Accordingly, it should be clearly understood that the embodiments described above are not intended as restrictions on the scope of the invention, which is limited only by the following claims.

What is claimed is:

1. An optical demultiplexer comprising:

a first optical path having a first nonlinear optical element (NLE) and a reflective mirror;

a second optical path having a second NLE and reflective mirror, the first and second NLE each being responsive to an optical control pulse to induce a phase shift in an optical data pulse propagating therethrough;

an optical coupler having an input port for concurrently coupling a train of optical data pulses onto said first and said second optical paths, said coupler being responsive to in-phase data pulses reflected from the first and second optical paths to provide an output data pulse on a first output terminal, and to phase-offset data pulses reflected from the first and second optical paths to provide an output data pulse on a second output terminal; and

a control circuit providing optical control pulses with predetermined timing to said first and second NLE to direct output data pulses to a select output terminal.

2. The optical demultiplexer of claim 1, wherein the NLE and reflective mirror in at least one optical path are integrated in a reflecting NLE.

3. The optical demultiplexer of claim 1, wherein the reflecting NLE is made from a semiconductor optical amplifier (SOA) with one reflecting surface.

4. The optical demultiplexer of claim 3, wherein the SOA is a vertical cavity surface emitting laser (VCSEL).

5. The optical demultiplexer of claim 2, wherein the reflecting NLE is a saturable Bragg reflector (SBR).

6. The optical demultiplexer of claim 1, wherein the NLE and the mirror in at least one optical path are physically separable components.

7. The optical demultiplexer of claim 1, wherein the first and second NLE respond to optical control pulses substantially instantaneously to induce a phase shift in an optical data pulse propagating therethrough.

8. The optical demultiplexer of claim 7, wherein the NLE response time is on the order of 100 femto seconds.

9. The optical demultiplexer of claim 1 further comprising a time delay line (TDL) for providing a timing offset in the application of optical control pulses to said first and second NLE.

10. The optical demultiplexer of claim 1, wherein said NLE in at least one optical path has one input port, and optical control and data pulses are provided to the said NLE through the input port.

11. The optical demultiplexer of claim 10 further comprising an optical coupler for coupling optical control and data pulses to be provided to the said NLE.

12. The optical demultiplexer of claim 11, wherein the optical coupler is a 90/10 coupler.

13. The optical demultiplexer of claim 1, wherein said NLE in at least one optical path has two input ports and optical control pulses and optical data pulses are provided to the said NLE through different input ports.

14. The optical demultiplexer of claim 1, wherein optical control pulses and optical data pulses are generated using one laser.

15. The optical demultiplexer of claim 1, wherein optical control pulses and optical data pulses are generated using synchronized lasers.

16. An optical demultiplexer comprising:

a coupler concurrently coupling a train of input optical data pulses to one end of a first and a second optical paths;

a first non-linear optical element (NLE) and an associated mirror at an opposite end of the first optical path and a second NLE and an associated mirror at an opposite end of the second optical path; and

a control circuit providing control signals that cause changes in the optical properties of the first NLE in a predetermined timing relationship to changes in the optical properties of the second NLE to direct in-phase optical pulses reflected from the first and the second optical paths to a select output terminal.

17. The optical demultiplexer of claim 16, wherein the NLE and reflective mirror in at least one optical path are integrated in a reflecting NLE.

18. The optical demultiplexer of claim 1, wherein the reflecting NLE is made from a semiconductor optical amplifier (SOA) with one reflecting surface.

19. The optical demultiplexer of claim 1, wherein the NLE and the mirror in at least one optical path are physically separable components.

20. The optical demultiplexer of claim 16, wherein the first and second NLE respond to optical control pulses substantially instantaneously to induce a phase shift in an optical data pulse propagating therethrough.

21. The optical demultiplexer of claim 16 further comprising a time delay line (TDL) for providing a timing offset in the application of optical control pulses to said first and second NLE.

22. The optical demultiplexer of claim 16, wherein optical control and optical data pulses are provided to the NLE in at least one optical path through the same input port.

23. The optical demultiplexer of claim 16, wherein optical control pulses and optical data pulses are provided to the NLE in at least one optical path through different input ports.

24. The optical demultiplexer of claim 16, wherein optical control pulses and optical data pulses are generated using one laser.

25. The optical demultiplexer of claim 1, wherein optical control pulses and optical data pulses are generated using synchronized lasers.

26. A method for optical demultiplexing comprising:

providing an input optical data pulse train comprising time-division multiplexed signals from a plurality of channels;

passing the input optical data pulse train concurrently through one end of a first and second optical paths, each path having at an opposite end a non-linear optical element (NLE) and an associated reflecting mirror;

applying an optical control pulse in a predetermined timing relationship to each NLE to cause reflected optical data pulses propagating through the first and second optical paths to interfere constructively at a selected output terminal.

27. The method of claim 26, wherein optical control pulses are applied to select optical data pulses from a predetermined channel.

28. The method of claim 26, wherein the NLE and reflective mirror in at least one optical path are integrated in a reflecting NLE.

29. The method of claim 26, wherein the NLE and the mirror in at least one optical path are physically separable components.

30. The method of claim 26, wherein the time-division multiplexed signals have terabit per second data rate range.

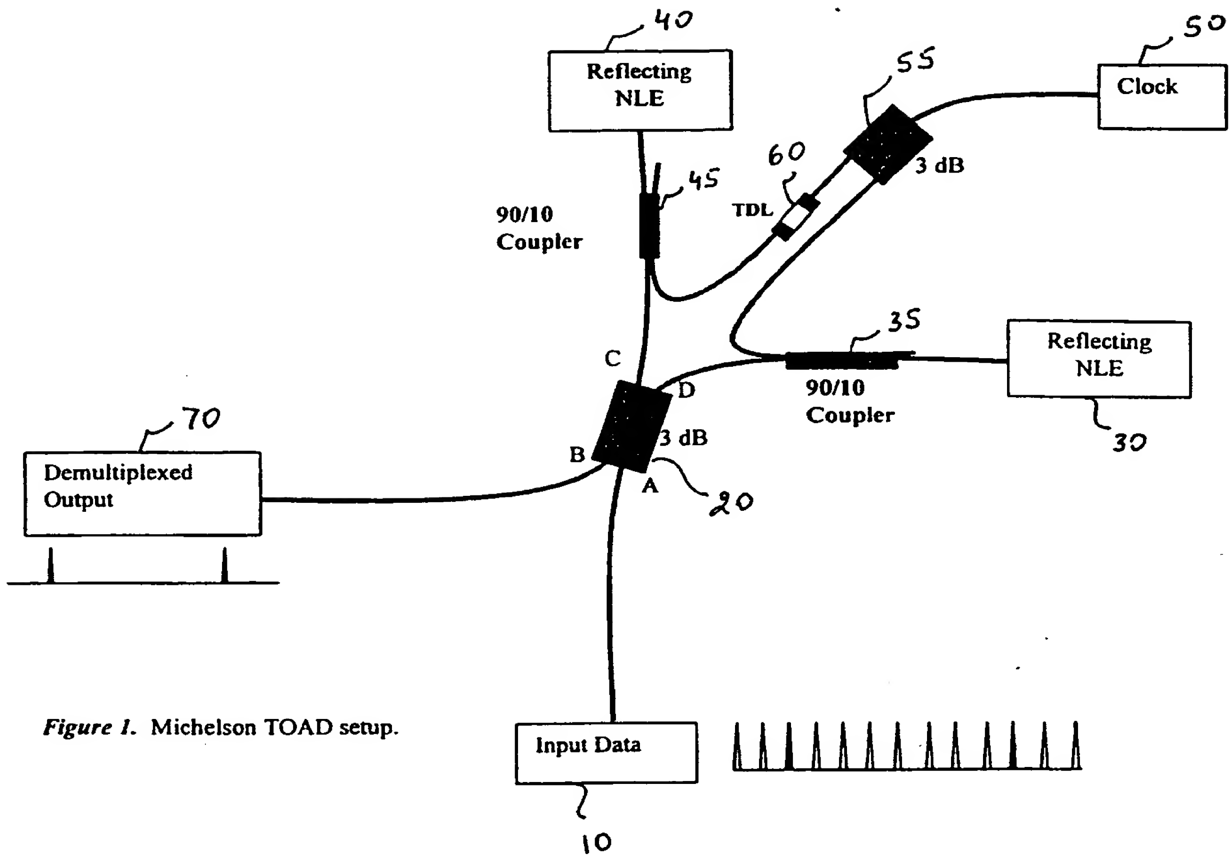


Figure 1. Michelson TOAD setup.

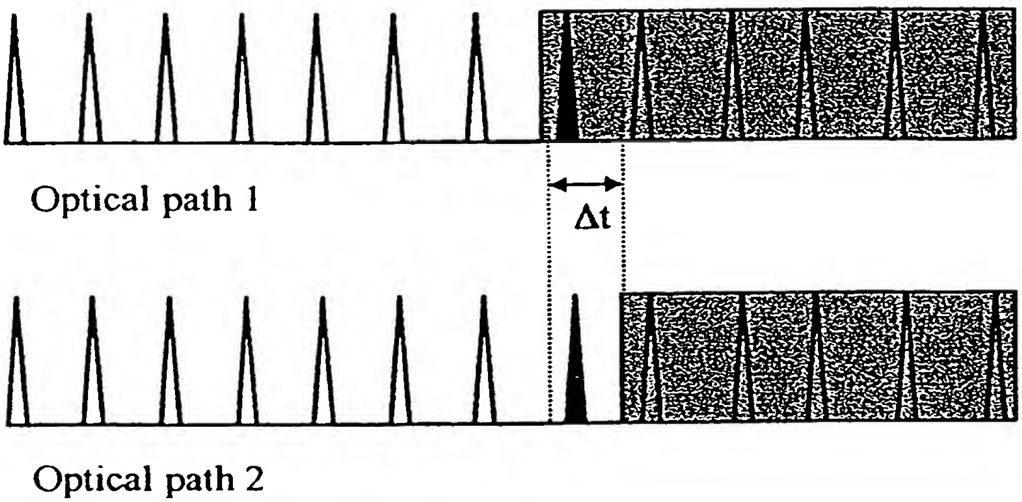


Figure 2.

Figure3. Michelson TOAD setup with control pulse injected through second port.

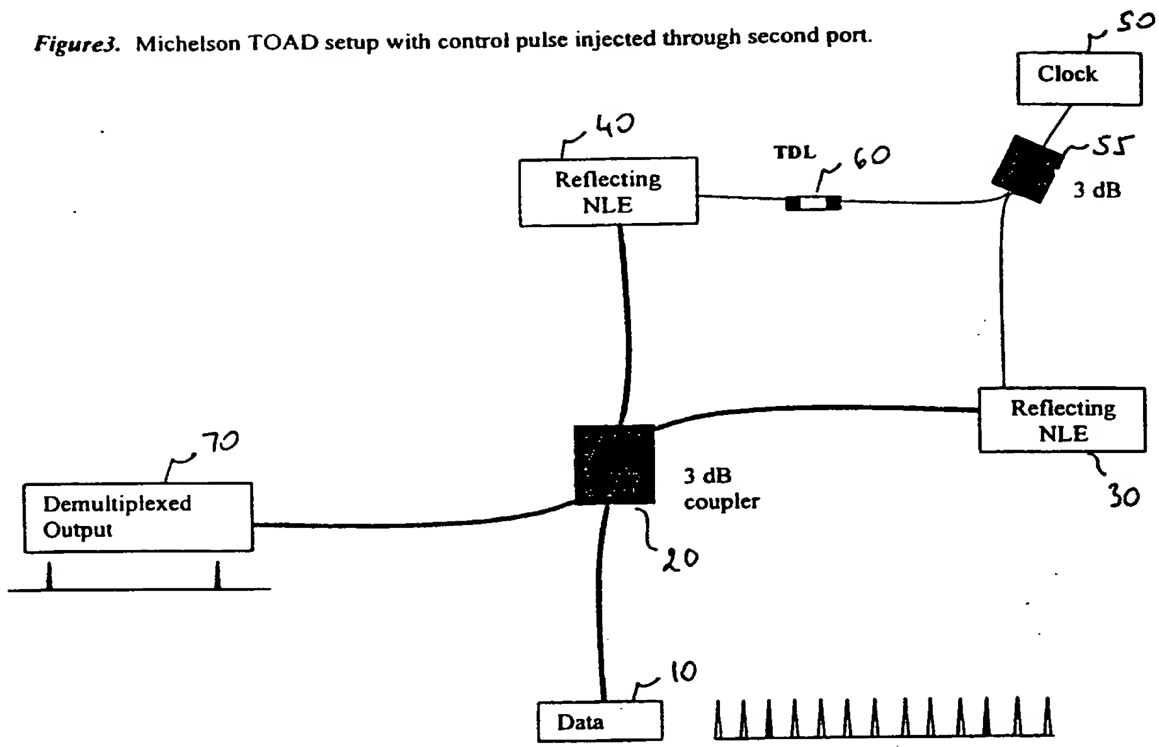


Figure 4. Michelson TOAD setup with control pulse injected through back.

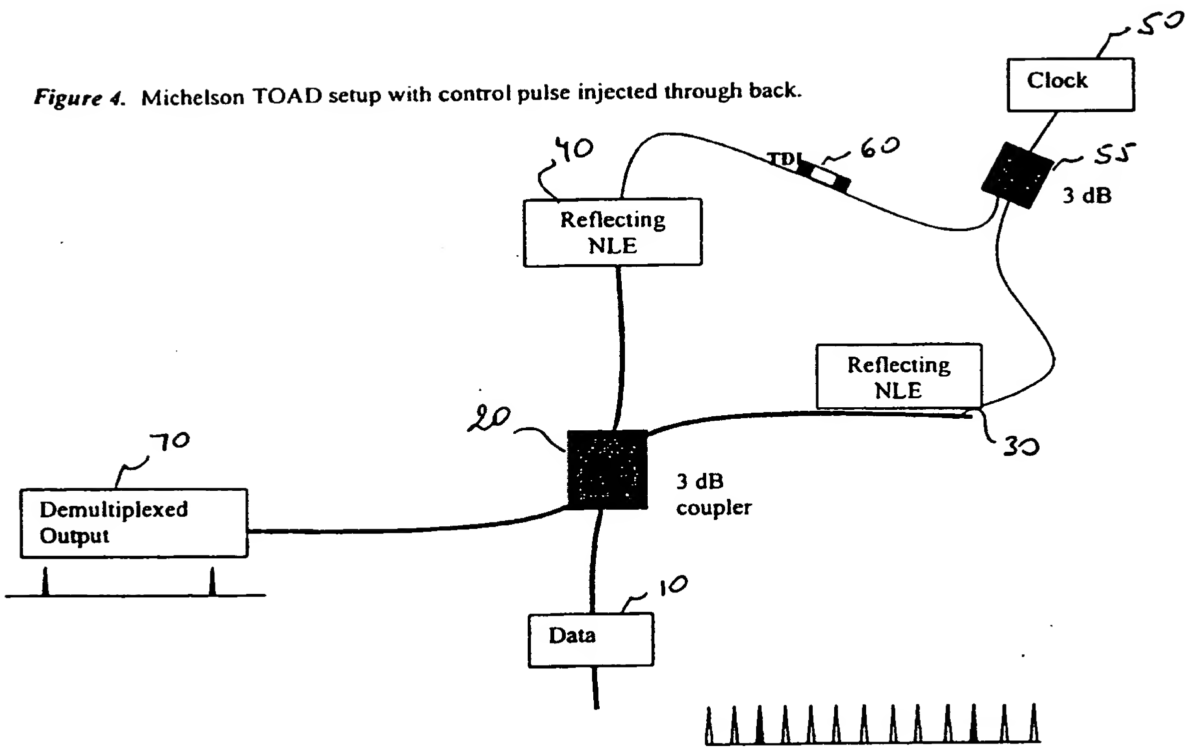
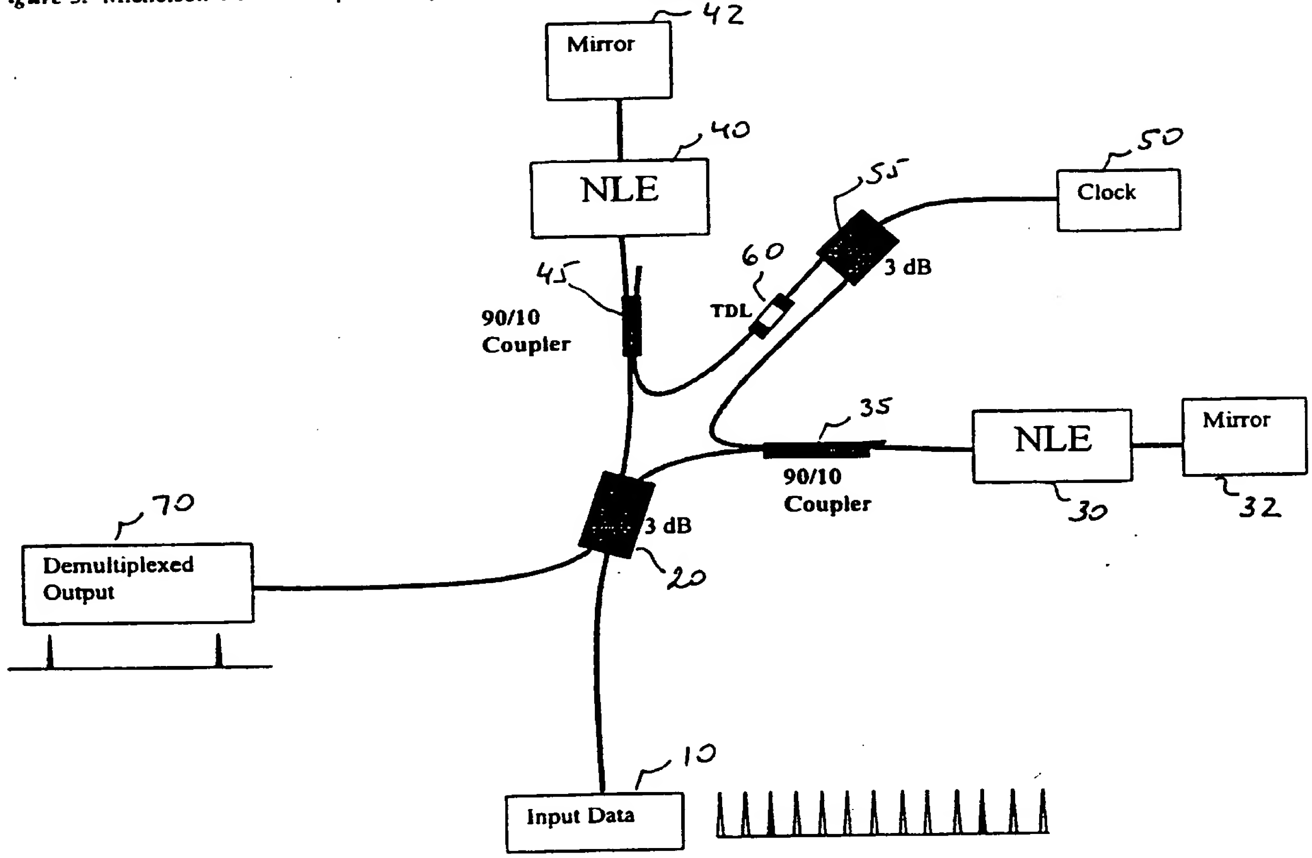


Figure 5. Michelson TOAD setup with separate mirror and nonlinear element.



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/18763

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :Please See Extra Sheet.
US CL : 359/127, 123, 279, 139, 128; 385/ 16, 15; 372/45, 99
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : 359/127, 123, 279, 139, 128; 385/ 16, 15; 372/45, 99

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST, WEST, TOAD, NOLM

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,825,519 A (PRUCNAL) 20 October 1998, Figs. 2 and 4, col. 2, lines 65-67, col. 3, lines 1-67, col. 4, lines 1-67, col. 5, lines 1-34.	1-30
Y, P	US 5,999,293 A (MANNING) 07 December 1999, Figs. 1, 3, and 4, col. 3, lines 16-67, col. 4, lines 1-67cols. 5 and 6, lines 1-67.	1-30
Y	US 5,742,415 A (MANNING et al) 21 April 1998, Fig. 1, col.3, lines 46-67, col. 4, lines 1-67.	1-3, 16-18, 26-28
Y	US 5,848,205 A (BIGO) 08 December 1998, Fig. 1, col. 1, lines 10-67, col. 2, lines 1-67.	1-3, 16-18, 26-28

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
22 AUGUST 2000	15 SEP 2000

Name and mailing address of the ISA/US	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/18763

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,701,327 A (CUNNINGHAM et al) 23 December 1997, Fig. 1, col. 3, lines 56-67, col. 4, lines 1-67, cols 5 and 6, lines 1-67.	5
Y	US 5,912,913 A (KONDOW et al) 15 June 1999, Fig. 2, col. 6, lines 40-67, cols. 7 and 8, lines 1-67.	4, 5
Y, E	US 6,097,529 A (LEE et al) 01 August 2000, Figs. 1, 3, and 4, col. 1, lines 1-67, col. 2, lines 1-67, cols. 3 and 4, lines 1-67.	1, 9, 16, 21, 26
Y	US 5,625,727 A (LIEDENBAUM et al) 29 April 1997, Figs. 2, 3, and 4, col. 5, lines 1-67, col. 7, lines 10-67, col. 8, lines 1-67, cols. 9 and 10 , lines 1-67.	10, 11, 13, 22, 23
Y	US 5,493,433 A (PRUCNAL et al) 20 February 1996, Figs. 1 and 3, col. 2, lines 64-67, col. 3, lines 1-67, col. 4, lines 1-67, col. 5, lines 1-67.	14, 15, 24 25

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/18763

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (7):

H04J 14/02, 14/08, 14/00; G02B 6/35, 6/26; G02F 1/01; H01S 3/08, 5/32